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Walter Greiner *Editor*

Nuclear Physics: Present and Future

FIAS Frankfurt Institute for Advanced Studies

Springer

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Preface

This book presents the majority of the talks delivered at the International Symposium *Nuclear Physics: Presence and Future*, which was held from May 29 to June 5, 2013 at Hotel Jakobsberg, Boppard am Rhein, Germany. The symposium was jointly organized by the Frankfurt Institute for Advanced Studies (FIAS), Frankfurt, Germany and Joint Institute for Nuclear Research (JINR), Dubna, Russia.

The symposium was dedicated to Prof. Mikhail Itkis on the occasion of his 70th birthday in recognition of his contributions as a pioneer in the fields of nuclear fission and superheavy nuclei and his commitment as a long-time director of the Flerov Laboratory at JINR, Dubna.

The main objective of the symposium was to present a survey of state-of-the-art topics in nuclear physics by leading practitioners in the field. A major focus was the study of superheavy nuclei and of neutron-rich exotic nuclei. The mechanisms of nuclear fission and nuclear cluster decay also were discussed by several speakers. Further subjects addressed were relativistic heavy ion collisions and the physics of supercritical fields. Transcending the subject of nuclear physics were talks dealing with the astrophysics of compact stars and with theoretical and experimental aspects of general relativity and its possible modification.

The symposium was held in the Jakobsberg resort near Boppard. This hotel is centrally located in one of Germany's most beautiful and picturesque landscapes—the Rhine Valley between Koblenz and Mainz. In fact, this famous wine-growing region has been designated as one of UNESCO's World Heritage sites.

I am grateful to my fellow members of the organizing committee from the Joint Institute for Nuclear Research in Dubna, Sergei Dimitriev and Dmitri Kamanin who helped to shape and organize the symposium. Joachim Reinhardt has edited the proceedings volume and was instrumental in bringing this book into a coherent

shape. Laura Quist has acted as the conference secretary and has helped in a multitude of ways to make the symposium a success. Finally, I am grateful to Dr. Thorsten Schneider and his team at Springer Verlag who expertly handled the production of this book.

Frankfurt, April 2014 Walter Greiner

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Dedication to Prof. Mikhail Itkis

Walter Greiner

This symposium is dedicated to Prof. Mikhail Itkis on the occasion of his 70th birthday. Our personal acquaintance dates back about three decades. I first met Mikhail Itkis at a conference on neutron physics, organized by Prof. Dieter Seeliger (Technische Hochschule at Dresden in East Germany: at that time "Deutsche Demokratische Republik") at a small castle about 40 km east of Dresden, near Bautzen. I gave a talk on collective theory of fission. The basic idea was that the essential coordinates of a fissioning nucleus are the distance R between the two nuclear centers and the mass asymmetry

$$\eta = \frac{A_1 - A_2}{A_1 + A_2},$$

where A_i are the number of nucleons in the ith fission fragments (see Fig. 1).

The potential between the two fragments $V(R, \eta)$ depends for given R on the mass asymmetry η. The collective wave-function $\Psi(R, \eta)$ will show maxima where the potential has minima and vice versa. The probability distribution will show pronounced maxima for symmetric and asymmetric fission. If the potential has several minima, e.g., due to shell structure, *symmetric*, *asymmetric* and *superasymmetric* fission will occur (see Figs. 2 and 3).

I was tremendously pleased when Professor Itkis stood up and showed a figure of his measurements of the fission products of various symmetrically fissioning nuclei, which showed side-maxima—see Fig. 4. Clearly, there was evidence for such superasymmetric fission: in this case it is a symmetrically fissioning nucleus which shows side-maxima in the asymmetry degree of freedom.

Later in time (2010–2012) Prof. Friedrich Gönnenwein (Tübingen) gave beautiful evidence for superasymmetric fission of various heavy nuclei, see Fig. 5. But it was Mikhail Itkis who discovered superasymmetric fission first. I was tremendously happy when these clear and lucid collective ideas found confirmation by Itkis' experiment.

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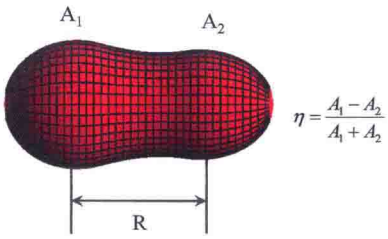

Fig. 1 The deformed nucleus fissioning into two clusters, R is the distance between the two clusters and η is the mass-asymmetry coordinate

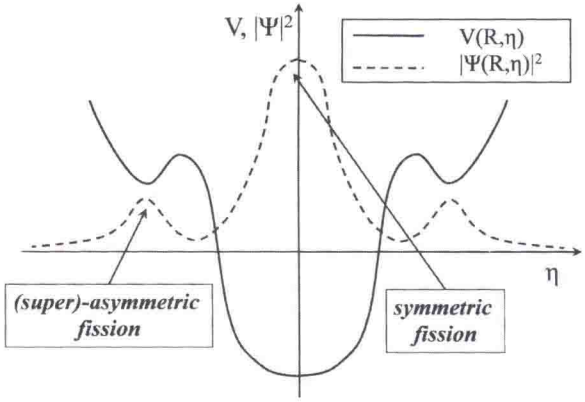

Fig. 2 Potential of a symmetrically fissioning nucleus as a function of the mass-asymmetry η (*solid line*). The collective wave function squared $|\Psi(R, \eta)|^2$ as a function of η at fixed R (*dashed line*)

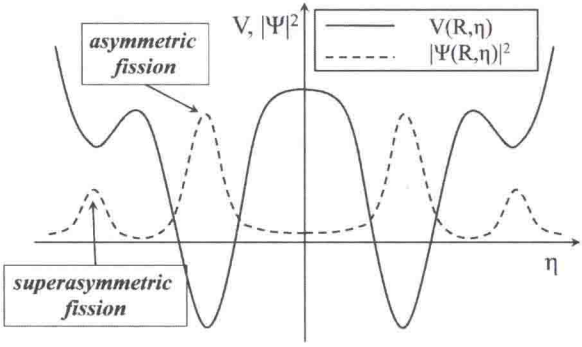

Fig. 3 Potential of an asymmetrically fissioning nucleus as a function of the mass-asymmetry η with additional possibility of superasymmetric fission

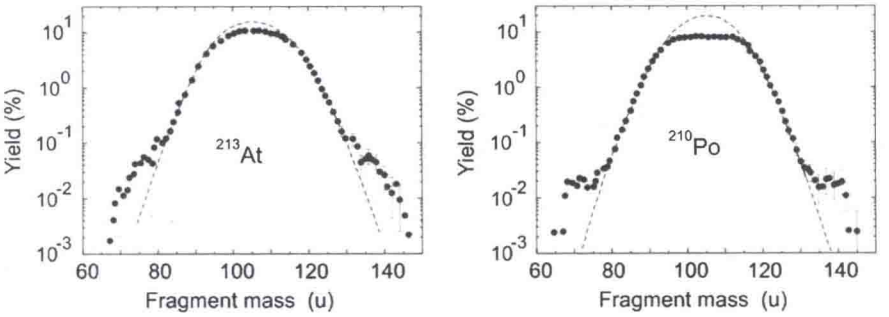

Fig. 4 Symmetrically fissioning nucleus with the contribution from superasymmetric fission

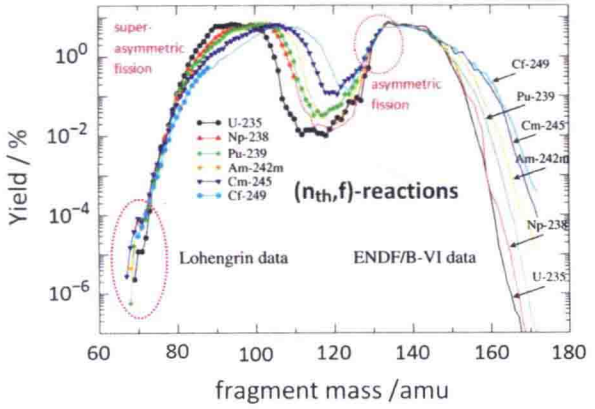

Fig. 5 Fragment distribution of asymmetrically fissioning nuclei with the indication of super-asymmetric fission

This is a master example where a simple theoretical idea was proven by a beautiful measurement—done independently of the theory.

Mikhail is a brilliant nuclear physicist, a dedicated researcher and science organizer, and at the same time a caring and warm person. A full appreciation of his scientific life will now be given. Andrej Popeko helped me in setting this up.

1 Prof. Mikhail Itkis—Pioneer of Nuclear Physics

Professor Mikhail Itkis was born on 7 December 1942 in Kazakhstan, then a socialist republic within the USSR. He graduated from the Moscow State University, where he majored in physics. In 1967 he started his academic career at the Institute of Nuclear Physics (INP) of the Republic of Kazakhstan, one of the scientific divisions of the Kazakhstan Academy of Sciences.

Professor Mikhail Itkis went through many challenges to get to where he is today. Initially the young scientist worked as an engineer in Almaty city (former Alma-Ata). He defended his Ph.D. and habilitation theses in 1974 and 1985, respectively. Professor Itkis became the head of one of the major departments at INP. He has been extensively studying nuclear fission for over 40 years, a topic which occupies one of the central positions in the universal many-body problems of nuclear physics. His work was widely recognized, and he became one of the leading nuclear fission scientists. The group of young Almaty scientists announced first, extremely promising results for nuclear fission, which helped deepen our knowledge of this process and of the properties of nuclear matter. The Almaty team presented experimentally measured fission barriers and moments of inertia of nuclei and studied shell-effect manifestation in mass-energy distributions of low-energy fission fragments.

Subsequently, the Almaty researchers conducted a series of experiments that enabled them to estimate the probability of preactinide nuclei fission. The results also helped the scientists determine the shape of nuclei in the regions of nuclear super-deformations and evaluate the impact of both the shell structure and the effects of the nuclear binding of nucleons on thermodynamic properties of hot nuclei.

These efforts started to bear fruit. The Almaty team observed new features of nuclear fission in the lead region which was crucial for a better understanding of the character of the asymmetric nuclear fission and the impact of both shell effects and the fluctuation-dissipation processes on the formation of mass and energy distributions of fission fragments from cold and hot nuclei.

As Mikhail Itkis was probing deeper into the process of nuclear fission induced by light-charged particles, it was in early 1980s when he discovered another promising field of research, namely, the fission of nuclear systems emerging from heavy-ion induced reactions. His academic interests were so intricately interwoven with the research activities at JINR that in 1992 he was invited to pursue his scientific activities at FLNR.

In 1993 the JINR Scientific Council appointed Professor Itkis a deputy director, and in 1997 he became the director of FLNR, JINR. Professor Itkis started intense research of nuclear fission induced by heavy ions at the U400 cyclotron and founded one of the laboratory experiment divisions intended the study of the reaction dynamics and fission of heavy and superheavy nuclei. Not only did Professor Itkis head the laboratory, but he also initiated and participated in many experiments.

The experiment division staff pioneered unique techniques and constructed a series of setups for evaluating the correlation between the neutron emission, gamma quanta, and fission fragments. The double-arm time-of-flight CORrelation SETup (CORSET) manufactured for this purpose proved to be extremely efficient. Subsequently, the coupling of the spectrometer of fission fragments CORSET with the DETecteur MOdulaire de Neutrons (DEMON), a Belgian-French neutron multi-detector, allowed use of the former as a trigger for multi-detector systems.

Such collaborative work increased the reliability of data on average neutron and gamma-quanta multiplicity in heavy-ion-induced reactions, which allowed for the first time ever separation of reaction channels. One of the key results was the discovery of quasifission processes in the fission of heavy nuclear systems. This breakthrough allowed correct interpretation of experimental constraints to nuclear fusion leading to the formation of superheavy nuclear systems. Over the years, the FLNR JINR staff conducted systematic investigations of fusion-fission and quasifission of heavy and superheavy nuclei at $Z = 102 - 122$ using the U400 cyclotron. Moreover, the FLNR researchers studied the excitation functions of nuclear reactions, the mass-energy distributions of reaction products, the multiplicities of neutrons and gamma-quanta, and the manifestation of shell effects in cold and hot fusion reactions.

The experiments by JINR FLNR found interesting results on estimates of fission cross sections for superheavy nuclei, which allowed for the study of the formation probability of compound nuclei. The choice of the most promising ion-target combinations and optimal excitation energy for the synthesis of superheavy elements was justified by the core assumptions of the theory.

As director of the Flerov Laboratory (1997–2007), Professor Itkis did his best to develop lab facilities and achieve further progress in the study of nuclear processes. Numerous changes were initiated, i.e., experimental laboratory equipment was expanded, new experimental setups were designed and constructed, superheavy elements 113–118 were synthesized, and their production was investigated. Mikhail Itkis started experiments dedicated to the study of chemical properties of new elements; the research was carried out on fission physics, nuclear reaction mechanisms, nuclear spectroscopy, and the properties of exotic nuclei. In May 2011 the International Union of Pure and Applied Chemistry (IUPAC) officially recognized flerovium and livermorium, elements 114 and 116, added to the Mendeleev periodic table. In May 2012

IUPAC officially approved the name flerovium for the superheavy element of atomic number 114 and the name livermorium for element 116.

Professor Itkis was awarded numerous JINR awards in recognition of his academic achievements. He won both the G.N. Flerov Prize 2003 and the Alexander von Humboldt Research Prize 2005 (Germany).

In 2009 Professor Itkis was honored to receive the degree of doctor honoris causa of the Goethe University, Frankfurt. In 2011, together with Professor Yuri Oganessian, Professor Itkis was awarded the 2010 State Prize of the Russian Federation for outstanding contributions in science and technology. In March 2006 the Committee of Plenipotentiaries of the JINR Member States appointed Professor Itkis as the JINR deputy director. Numerous presentations at this conference today are in fields to which Professor Itkis made a number of ground-breaking contributions.

Professor Itkis is known for his fundamental work in various fields of physics that played a key role in the establishment and development of many areas of further research. To us, his friends and colleagues, Mikhail is much more than an outstanding scientist. He is a warm and caring friend, a wonderful colleague who gave freely of his time, advice and expertise. From the bottom of our hearts, we would like to congratulate Mikhail on his 70th anniversary. We all wish him good health and new outstanding achievements.

Part I
Superheavy Elements